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MULTIYEAR LOW FLOW OF STREAMS IN NORTHEASTERN KANSAS

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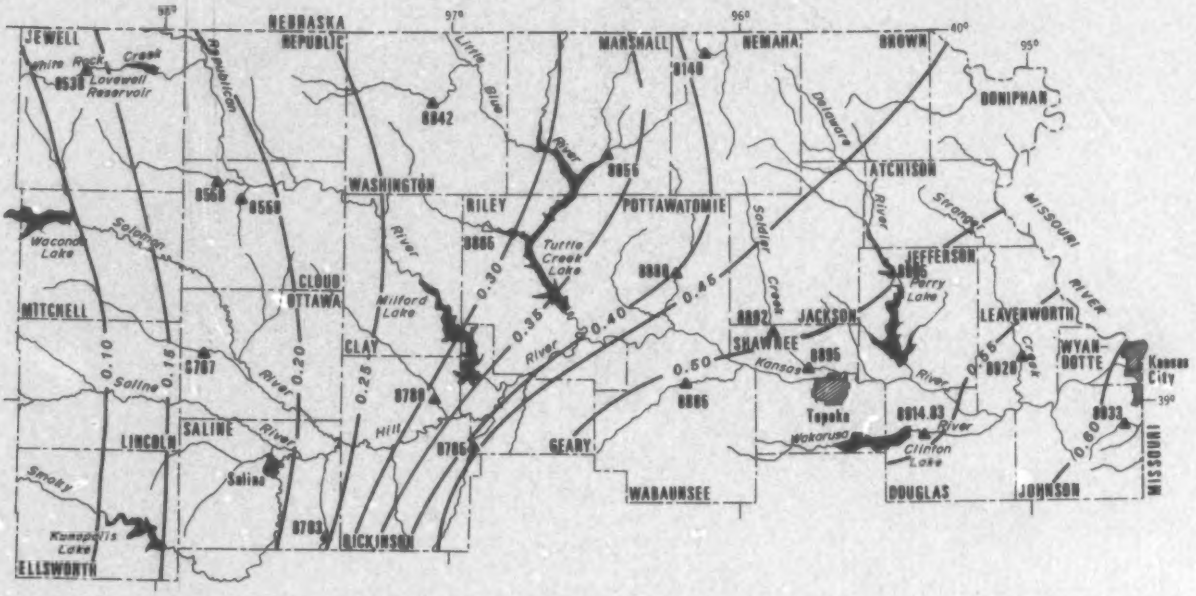

Prepared in cooperation with
the Kansas Water Resources Board

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GEOLOGICAL SURVEY

MULTIYEAR LOW FLOW OF STREAMS IN NORTHEASTERN KANSAS

By W. J. Carswell, Jr. and S. V. Bond

U.S. GEOLOGICAL SURVEY

WATER-RESOURCES INVESTIGATIONS

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Prepared in cooperation with the

Kansas Water Resources Board

Lawrence, Kansas
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MULTIYEAR LOW FLOWS OF STREAMS IN NORTHEASTERN KANSAS

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ABSTRACT

Many existing water supplies in northeastern Kansas are proving inadequate to meet current and expanded future needs. One of the methods in which the use of highly variable streamflow in the area can be evaluated is with the aid of multiyear low-flow frequency information. Using data from 19 streamflow-gaging stations in the study area, maps were developed from which the mean annual discharge and discharges for the 2- and 50-year recurrence interval for durations of 12, 24, 36, 48, and 60 months can be obtained for ungaged rural sites that have drainage areas of less than 1,000 square miles. Discharges for intervening recurrence intervals can be obtained by interpolation. Extrapolation of regionalized discharges to drainage areas smaller than about 50 square miles and larger than about 1,000 square miles has not been validated.

INTRODUCTION

Future economic advances and population growth in Kansas will result in increased demands on the limited water resources of the State, particularly during periods of drought. Many communities and other water users experienced shortages during the drought of 1976-77. These users recognize the need for expanding water supplies by development of new ground- or surface-water sources, or by constructing new or increased reservoir storage.

Many rural areas and cities in northeastern Kansas, which experienced water shortages during the moderate and severe droughts of recent years, have a pressing need for additional water supplies. In most of the area, ground water is not available in sufficient quantity or adequate quality for municipal, industrial, or rural water district supplies. Thus, strong consideration must be given to surface-water reservoirs of adequate size to meet expanding needs.

The U.S. Army Corp of Engineers, in cooperation with the Kansas Water Resources Board, is studying the potential use of small reservoirs in northeastern Kansas to satisfy water-supply needs, and comparing the results with other possible solutions. The Kansas Water Resources Board requested the U.S. Geological Survey to prepare a supplement to the report on storage requirements by Furness (1962) that will reflect subsequent streamflow data. Specifically, the purpose of this report is to provide multiyear low-flow frequency data for selected gaged sites, and to develop a method for estimating multiyear low-flow frequency data for ungaged sites. The study is restricted to unregulated streams in northeastern Kansas having drainage areas of less than 1,000 square miles.

CONVERSION TABLE

For those readers who may prefer to use metric units rather than inch-pound units, the conversion factors and abbreviations for the terms used in this report are listed below:

Multiply	By	To obtain
square mile (mi^2)	2.590	square kilometer (km^2)
cubic foot per second (ft^3/s)	0.028	cubic meter per second (m^3/s)
cubic foot per second per square mile [$(ft^3/s)/mi^2$]	0.011	cubic meter per second per square kilometer [$(m^3/s)/km^2$]

ACKNOWLEDGMENTS

The information contained in this report is based on data collected by the U.S. Geological Survey in cooperation with State and Federal agencies. The report was prepared in cooperation with the Kansas Water Resources Board.

GENERAL DESCRIPTION OF STUDY AREA

As described by Schoewe (1949, p. 288-311), northeastern Kansas lies primarily in the Osage Plains, Dissected Till Plains, and Dissected High Plains sections of the Central Lowland province, as shown in figure 1. The western part of the study area is in the Dissected High Plains section of the Great Plains province. The topography of the Osage Plains in northeastern Kansas is gently rolling with broad benches developed in some areas. The Dissected Till Plains are gently undulating with an erosional drift-controlled surface. The topography of the Dissected High Plains ranges from rolling, with flat plateau-like surfaces, to indistinct terraces and dissected escarpments.

The study area is primarily drained by the Kansas River and other tributaries of the Missouri River (fig. 2). This area contains approximately 18,000 square miles in all or most of 27 counties in northeastern Kansas.

AVAILABILITY OF STREAMFLOW DATA

Analyses described in this report are based on streamflow records at 19 gaging stations in northeastern Kansas with drainage areas of less than 1,000 square miles that have approximately 20 or more years of record of unregulated flow (fig. 2). Data used in the study were retrieved from the U.S. Geological Survey Watstore File (Hutchinson, 1975).

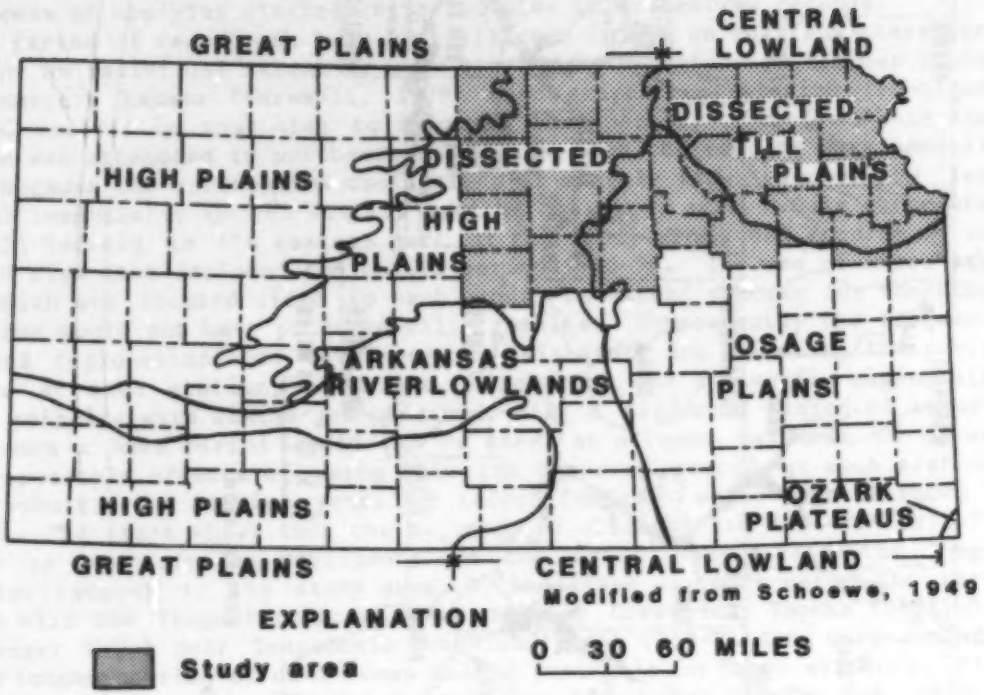

Figure 1.--Physiographic map of Kansas showing location of study area.

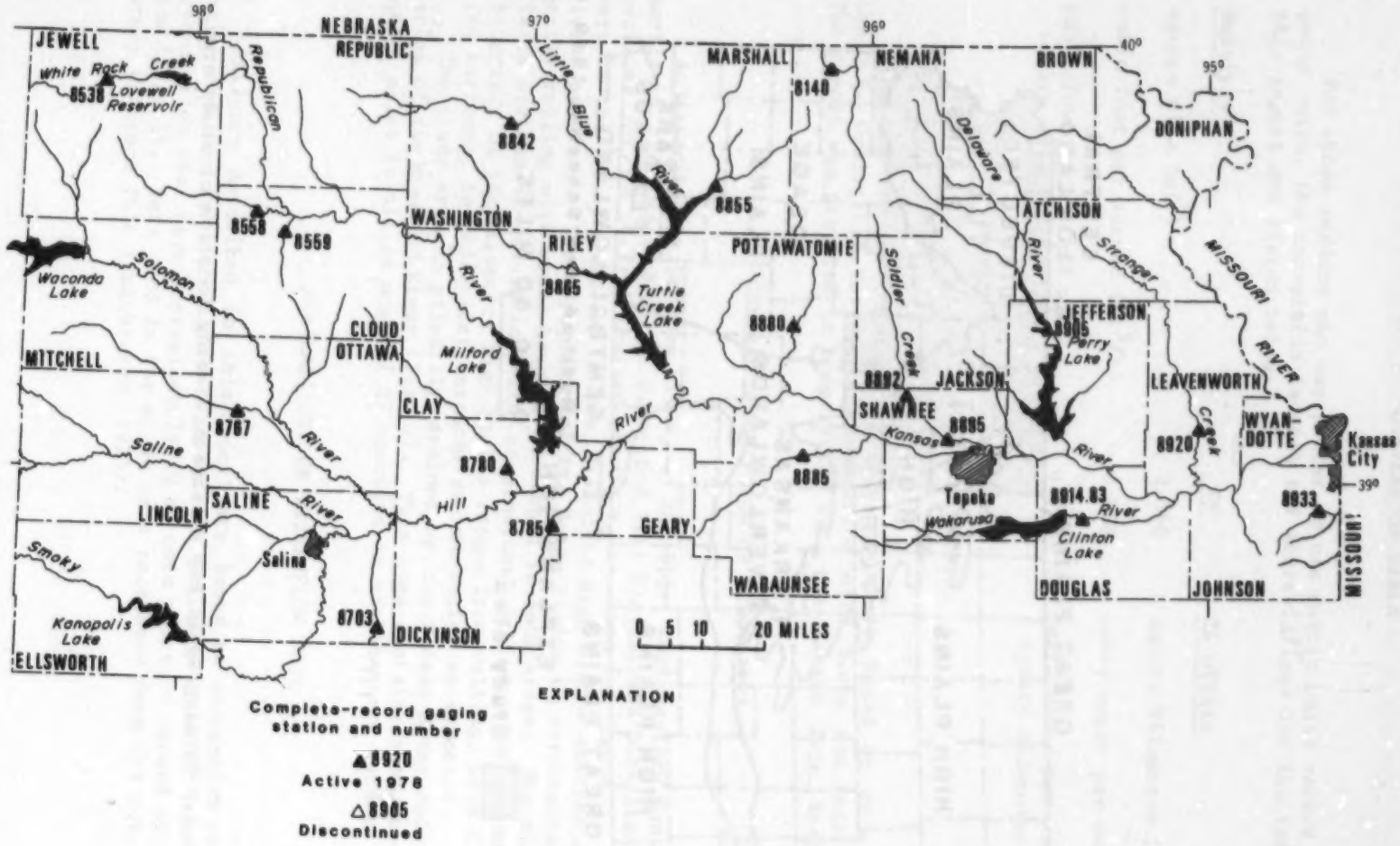

Figure 2.--Major streams draining northeastern Kansas and location of gaging stations used in the study.

LOW-FLOW FREQUENCY DATA FOR MULTIYEAR PERIODS

The storage requirement for sustaining a selected gross reservoir outflow is a function of the amount and time distribution of the inflow. Therefore, the chance of deficiency in outflow from a reservoir can be evaluated from the frequency and duration of periods of natural low flow. Periods of flow of less than 1 year are inadequate for defining storage requirements where long periods of storage are needed to develop the optimum use of the water. Therefore, drought flows for longer periods of consecutive months must be evaluated. The frequency characteristics of multiyear low flows may be developed by an extensive process of applying statistical principles to streamflow records.

The period of record can have a significant impact on the flow characteristics for an individual stream or many streams in a region. A similar study in southeastern Kansas (Carswell, 1979) used graphic correlation techniques to extend records in that area to a common base period, 1940-78. This same procedure was attempted in northeastern Kansas, but the results were unsatisfactory because the correlation coefficient of monthly flows was too low (less than 0.5), especially in the western part of the study area. Only three stations, all located in the eastern part of the study area, had records of unregulated flow that included the entire period 1940-78. The use of these stations, which are located close to each other, to extend records for the other 16 stations would not have produced valid results. Consequently the frequency curves and regionalizations developed in this study are based on the period of record at each station; therefore, discharges for a specific gaging site may not coincide with discharges obtained using a different period of record.

Because a base period could not be used, an attempt was made to determine the possible effects of using only the observed record at each station. The distribution of station years of record for each water year is shown in figure 3. The graph shows that the majority of stations had data for 1953-78. In order to ascertain how representative the period 1953-78 is of the longer streamflow records in the study area, a comparison was made using the three stations with the longest records. For Soldier Creek near Topeka (06889500) and Stranger Creek near Tonganoxie (06892000), the 1953-78 data were compared with the longest period of continuous record available for those stations, 1935-78 and 1930-78, respectively. For the Wakarusa River near Clinton Dam, 1953-77 was compared with the longest period of continuous record available, 1929-77 (flow regulated beginning in 1978 water year). Results showed that little change in the low-flow frequency curves occurred by using the shorter period of record. Mean annual discharge for the shorter period of record differed by less than 4 percent compared to the long-term mean at each of the three stations. Based on these comparisons, the use of the observed record for each station in the study area rather than a base period does not adversely affect either the mean annual discharge or the position of the low-flow frequency curves.

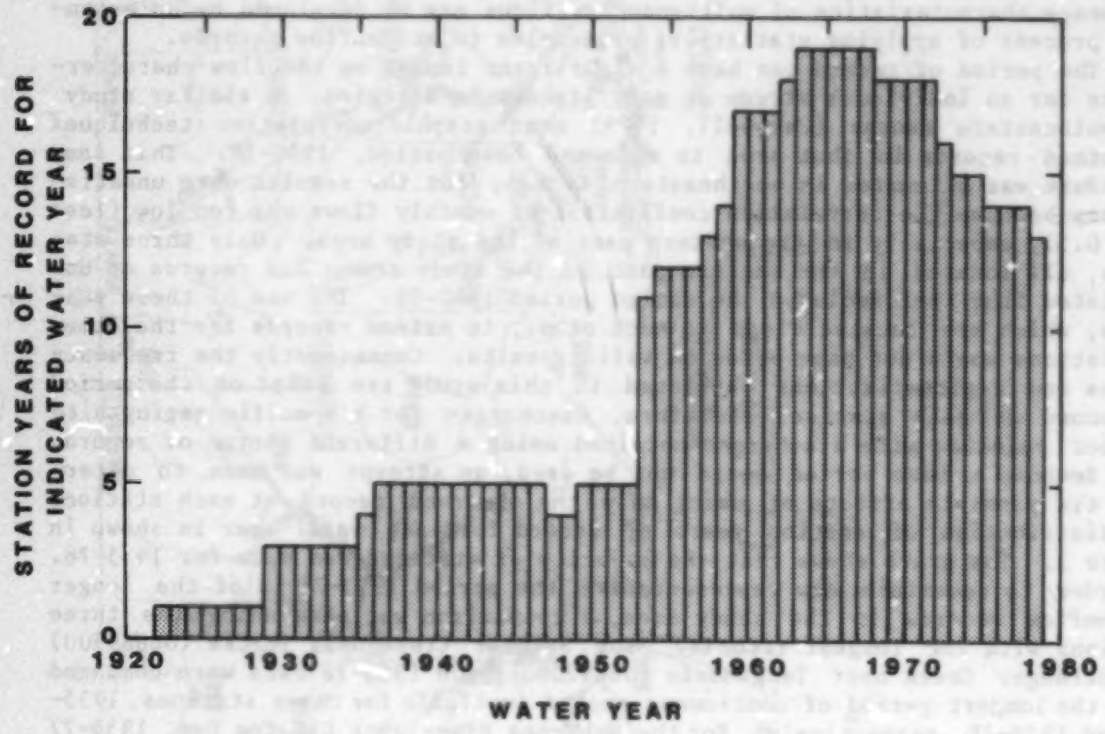

Figure 3.--Distribution of station years of record for each water year used in the study.

METHODS OF ANALYSIS

One universally accepted method for determining frequency of low flows for multiyear durations has not been established because various interpretations and assumptions are possible and no method has been shown to be clearly better than the others. The frequency determinations in this study were made using the method described by Furness (1962, p. 165-175). Low-flow data for independent 12-, 24-, 36-, 48-, and 60-month periods were determined using a digital-computer program based on the method developed by Hudson and Roberts (1955). In this procedure, the lowest 12-month moving average is selected, and overlapping moving averages are eliminated from further consideration. This process is continued until the data set is exhausted. Other durations are handled in a similar manner. Computed discharges are then divided by the drainage area to convert the discharges to cubic feet per second per square mile.

The recurrence interval (RI) against which the discharges were plotted was determined by the following formula (Furness, 1962):

$$RI = \frac{N - t + 2}{m} , \qquad (1)$$

in which N is the number of years of record; t is the duration of the period in years; and m is the rank order of the discharge starting with the lowest as number 1. This formula is similar to that for 1-year events

$$RI = \frac{N + 1}{m} , \qquad (2)$$

but acknowledges that in a 50-year period, for example, there are only forty-seven 4-year means.

Considerable judgment was exercised in drawing the trial frequency curves. Of most concern were the extremely low plotting positions of the minimum discharges, which commonly occurred during the extreme drought of the mid-1950's. Weather records indicate that this drought may have been the worst in 100 years or more. Thus, the curves were generally drawn above the minimum discharges. Sets of multiyear low-flow frequency curves were developed for each long-term gaging station. An example of the curves developed for Stranger Creek near Tonganoxie (06892000) is shown in figure 4.

The curves were adjusted for position with respect to mean annual discharge and for statistical distribution as described by Furness (1962). Resultant discharges are presented for selected recurrence intervals and durations in table 1. Only the 12- and 24-month discharges are given in table 1 for the Indian Creek at Overland Park station. The data from this station reflect the expansion of an urban environment in the basin. Consequently, the longer duration multiyear curves could not be properly adjusted for statistical distribution.

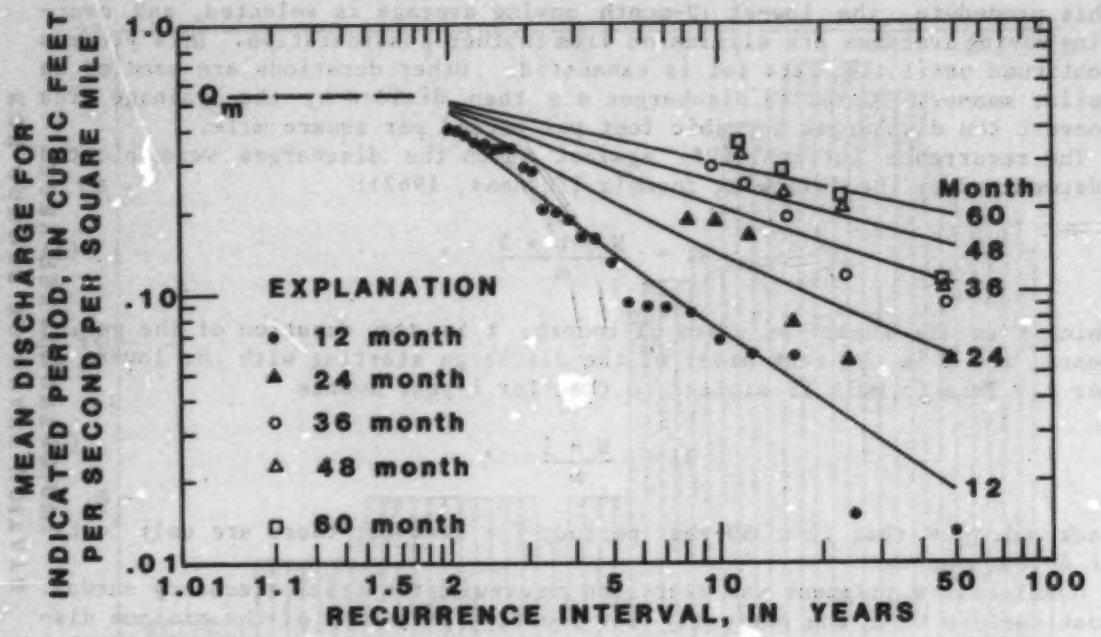

Figure 4.--Multiyear low-flow curves for Stranger Creek near Tonganoxie, 1930-78.

Table 1.--Minimum multiyear discharges expected at selected streamflow-gaging stations in northeastern Kansas

Gaging station	Drainage area (mi^2)	Average recurrence interval (yr)	Lowest mean discharge for indicated number of consecutive months [$(ft^3/s)/mi^2$]				
			12	24	36	48	60
06814000	276	2	0.250	0.319	0.350	0.366	0.377
TURKEY CREEK		5	.077	.161	.218	.264	.292
near Seneca		10	.035	.100	.159	.209	.246
Records analyzed 1949-78		20	.016	.063	.116	.168	.205
		50	.0054	.034	.075	.123	.160
06853800	227	2	.078	.090	.095	.098	.100
WHITE ROCK CREEK		5	.025	.045	.060	.069	.078
near Burr Oak		10	.013	.031	.045	.057	.068
Records analyzed 1958-78		20	.0077	.022	.036	.048	.060
		50	.0045	.015	.027	.039	.051
06855800	330	2	.099	.126	.142	.152	.159
BUFFALO CREEK		5	.054	.083	.098	.110	.121
near Jamestown		10	.036	.061	.075	.089	.101
Records analyzed 1955-78		20	.024	.044	.058	.071	.084
		50	.013	.027	.040	.053	.066
06855900	56	2	.128	.148	.158	.165	.169
WOLF CREEK		5	.026	.051	.070	.086	.099
near Concordia		10	.011	.027	.043	.058	.071
Records analyzed 1962-78		20	.005	.015	.027	.039	.051
		50	.0019	.0068	.015	.024	.034
06870300	120	2	.190	.201	.206	.208	.209
GYPSUM CREEK		5	.054	.100	.130	.150	.165
near Gypsum		10	.024	.062	.093	.119	.139
Records analyzed 1955-71		20	.012	.038	.067	.093	.118
		50	.0042	.020	.043	.068	.094
06876700	384	2	.071	.095	.106	.113	.117
SALT CREEK		5	.020	.037	.054	.066	.078
near Ada		10	.0085	.021	.035	.048	.060
Records analyzed 1959-78		20	.0037	.012	.023	.035	.047
		50	.0013	.0061	.014	.024	.034

Table 1.--Minimum multiyear discharges expected at selected streamflow-gaging stations in northeastern Kansas--Continued

Gaging station	Drainage area (mi^2)	Average recurrence interval (yr)	Lowest mean discharge for indicated number of consecutive months [$(ft^3/s)/mi^2$]				
			12	24	36	48	60
06878000	300	2	0.180	0.218	0.233	0.243	0.248
CHAPMAN CREEK		5	.100	.139	.170	.190	.205
near Chapman		10	.059	.098	.132	.160	.180
Records analyzed 1954-78		20	.032	.070	.105	.133	.155
		50	.014	.044	.075	.105	.128
06878500	230	2	.355	.399	.418	.427	.433
LYON CREEK		5	.110	.198	.260	.302	.340
near Woodbine		10	.044	.120	.185	.240	.280
Records analyzed 1954-74		20	.017	.072	.132	.190	.235
		50	.0049	.037	.084	.139	.185
06384200	344	2	.150	.184	.203	.215	.224
MILL CREEK		5	.056	.094	.118	.138	.155
at Washington		10	.031	.063	.085	.105	.121
Records analyzed 1960-78		20	.020	.044	.063	.081	.098
		50	.013	.028	.043	.059	.074
06885500	410	2	.214	.259	.278	.289	.295
BLACK VERMILLION RIVER		5	.075	.137	.182	.218	.239
near Frankfort		10	.034	.087	.138	.178	.202
Records analyzed 1954-78		20	.015	.056	.102	.147	.175
		50	.005	.032	.070	.112	.145
06886500	174	2	.220	.241	.249	.253	.256
FANCY CREEK		5	.037	.085	.110	.131	.150
at Winkler		10	.013	.044	.066	.087	.107
Records analyzed 1954-71		20	.0058	.024	.040	.059	.078
		50	.0025	.011	.022	.036	.053
06888000	243	2	.260	.303	.321	.331	.337
VERMILLION CREEK		5	.061	.117	.163	.200	.231
near Wamego		10	.020	.056	.097	.137	.173
Records analyzed 1936-46, 1954-72		20	.0061	.026	.056	.092	.130
		50	.0012	.0088	.026	.055	.087

Table 1.--Minimum multiyear discharges expected at selected streamflow-gaging stations in northeastern Kansas--Continued

Gaging station	Drainage area (mi^2)	Average recurrence interval (yr)	Lowest mean discharge for indicated number of consecutive months [$(ft^3/s)/mi^2$]				
			12	24	36	48	60
06888500	316	2	0.469	0.497	0.508	0.513	0.517
MILL CREEK		5	.177	.250	.320	.370	.405
near Paxico		10	.066	.142	.225	.290	.340
Records analyzed 1954-78		20	.020	.080	.158	.230	.290
		50	.0032	.036	.097	.169	.229
06889200	157	2	.392	.461	.491	.507	.516
SOLDIER CREEK		5	.140	.250	.310	.360	.390
near Delia		10	.089	.180	.240	.290	.330
Records analyzed 1959-78		20	.063	.138	.190	.239	.280
		50	.035	.099	.139	.185	.225
06889500	290	2	.335	.376	.398	.412	.421
SOLDIER CREEK		5	.092	.145	.184	.216	.245
near Topeka		10	.039	.079	.112	.142	.172
Records analyzed 1935-78		20	.018	.044	.070	.098	.127
		50	.0072	.021	.038	.059	.083
06890500	922	2	.300	.346	.365	.375	.382
DELAWARE RIVER		5	.110	.175	.220	.260	.285
at Valley Falls		10	.060	.118	.163	.205	.237
Records analyzed 1922-67		20	.034	.081	.122	.168	.200
		50	.017	.050	.086	.127	.159
06891483	412	2	.405	.424	.435	.441	.446
WAKARUSA RIVER		5	.063	.114	.182	.225	.255
below Clinton Dam		10	.034	.059	.109	.150	.180
Records analyzed 1929-77		20	.022	.037	.068	.100	.130
		50	.010	.023	.040	.062	.085
06892000	406	2	.425	.471	.489	.499	.505
STRANGER CREEK		5	.142	.220	.286	.330	.370
near Tonganoxie		10	.073	.141	.209	.260	.300
Records analyzed 1930-78		20	.040	.095	.155	.201	.248
		50	.020	.059	.108	.150	.190

Table 1.--Minimum multiyear discharges expected at selected streamflow-gaging stations in northeastern Kansas--Continued

Gaging station	Drainage area (mi^2)	Average recurrence interval (yr)	Lowest mean discharge for indicated number of consecutive months [$(ft^3/s)/mi^2$]				
			12	24	36	48	60
06893300	26.6	2	0.720	0.762	0.790	0.818	0.830
INDIAN CREEK		5	.302	.465	---	---	---
at Overland Park		10	.200	.333	---	---	---
Records analyzed 1964-78		20	.145	.245	---	---	---
		50	.100	.162	---	---	---

REGIONALIZATION OF RESULTS

Regionalization of results was accomplished by plotting on maps the mean annual discharges and the 2-year and 50-year low-flow discharges for each duration. The discharges were plotted at the centroid of the drainage for each station. Lines of equal discharge were then drawn in northeastern Kansas for specified frequencies and durations (figs. 5-15). Data available from a similar study in southeastern Kansas (Carswell, 1979) were used in developing the regionalizations so that the two studies would be in agreement at their common boundary. By interpolating between lines of equal discharge, these figures can be used to estimate multiyear low-flow frequency curves at ungaged sites. Discharges for frequencies between the 2- and 50-year recurrence interval can be obtained from a log-Gumbel plot of these estimates.

The data represent drainage areas of 56 to 922 square miles. Within this range, multiyear discharges, in terms of cubic feet per second per square mile, were not found to be related to size of drainage area. Therefore, the presentation of discharges in these units seems to be a valid aid to generalization and estimation for ungaged rural sites. However, extrapolation to drainage areas smaller than about 50 square miles or larger than about 1,000 square miles has not been validated.

SUMMARY

Many existing water supplies in northeastern Kansas are proving inadequate to meet current and expanded future needs. Estimates of multiyear low-flows can be used as one of the methods to evaluate the highly variable streamflow for water-supply use.

Presented in this report are maps from which the mean annual discharge and discharges for the 2- and 50-year recurrence interval for durations of 12, 24, 36, 48, and 60 months can be obtained for ungaged sites. Discharges for intervening recurrence intervals may be obtained by interpolation on a log-Gumbel plot. These maps were developed using data from 19 streamflow-gaging stations in the study area. Extrapolation of regionalized discharges in this report to rural drainage areas smaller than about 50 square miles and larger than about 1,000 square miles has not been validated.

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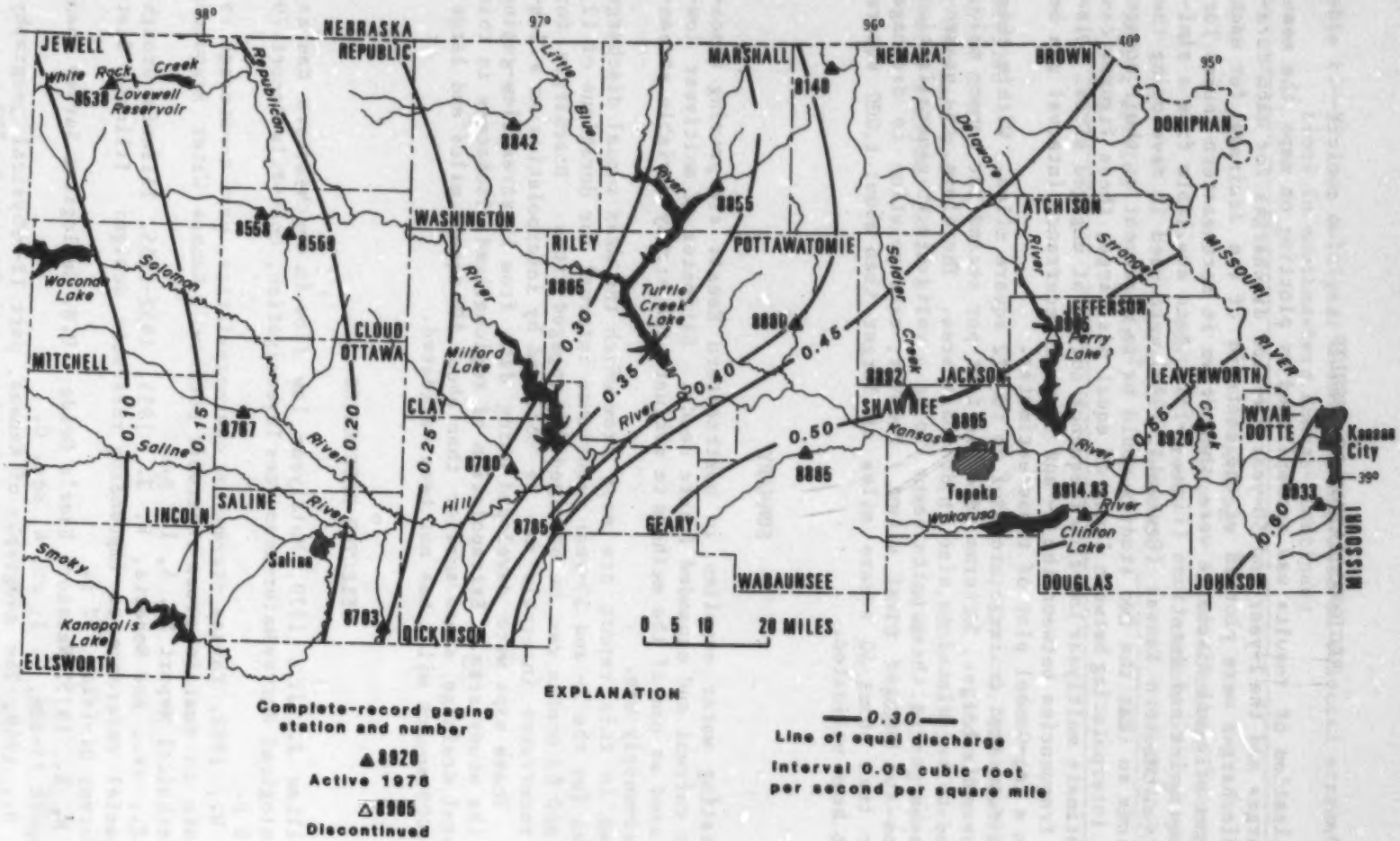

Figure 5.--Regional trend of mean annual discharge.

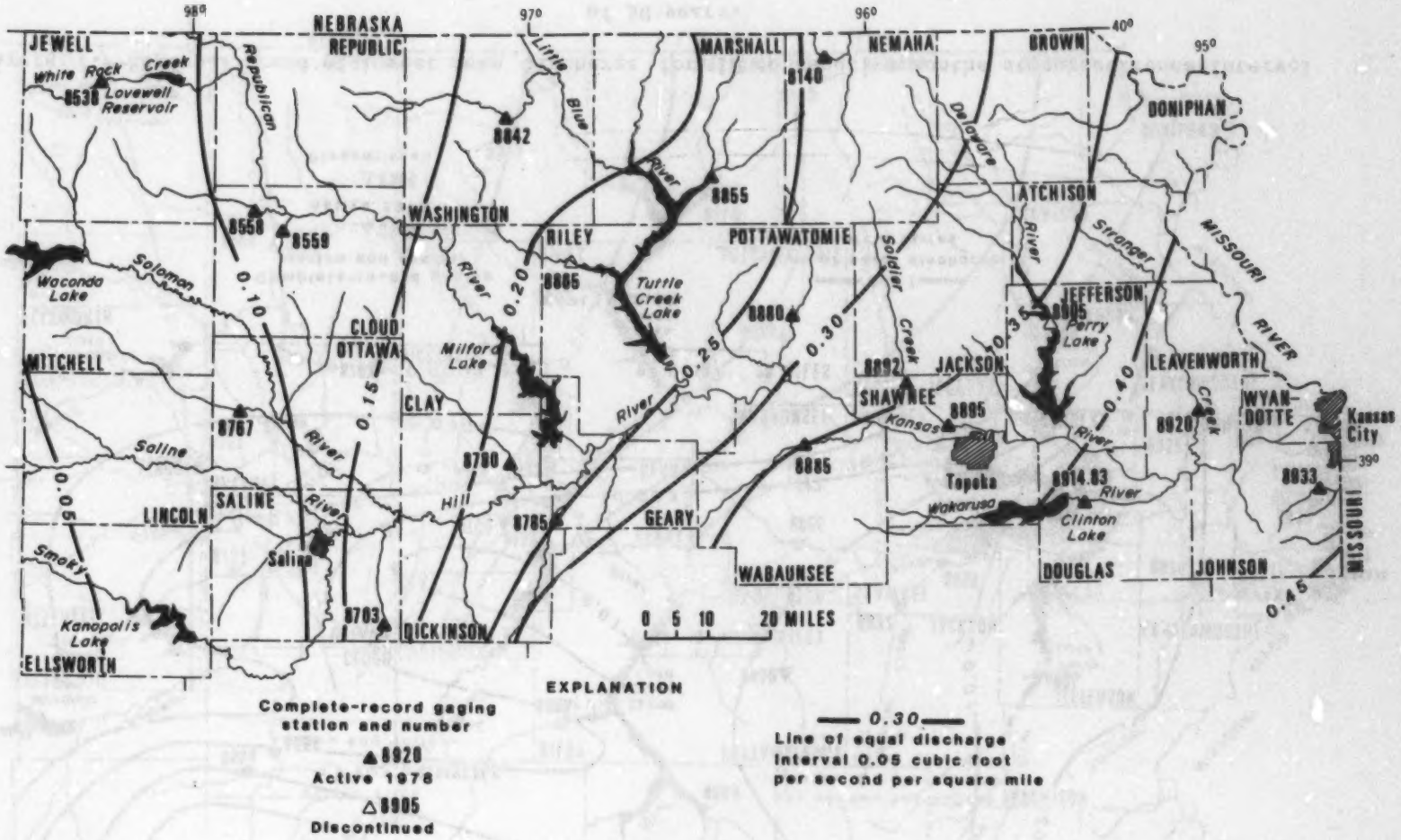

Figure 6.--Regional trend of lowest mean discharge for 12 consecutive months at a recurrence interval of 2 years.

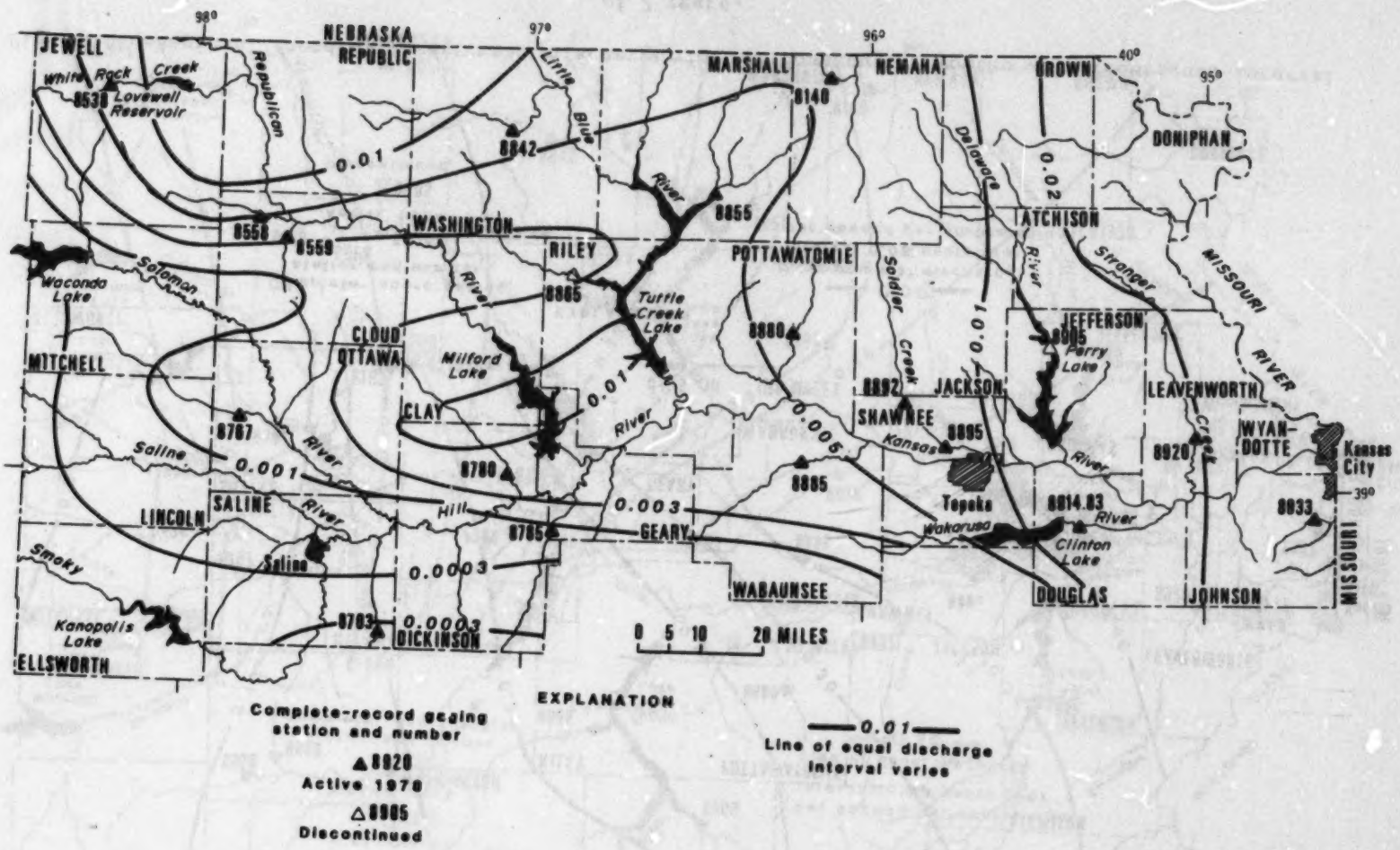

Figure 7.--Regional trend of lowest mean discharge for 12 consecutive months at a recurrence interval of 50 years.

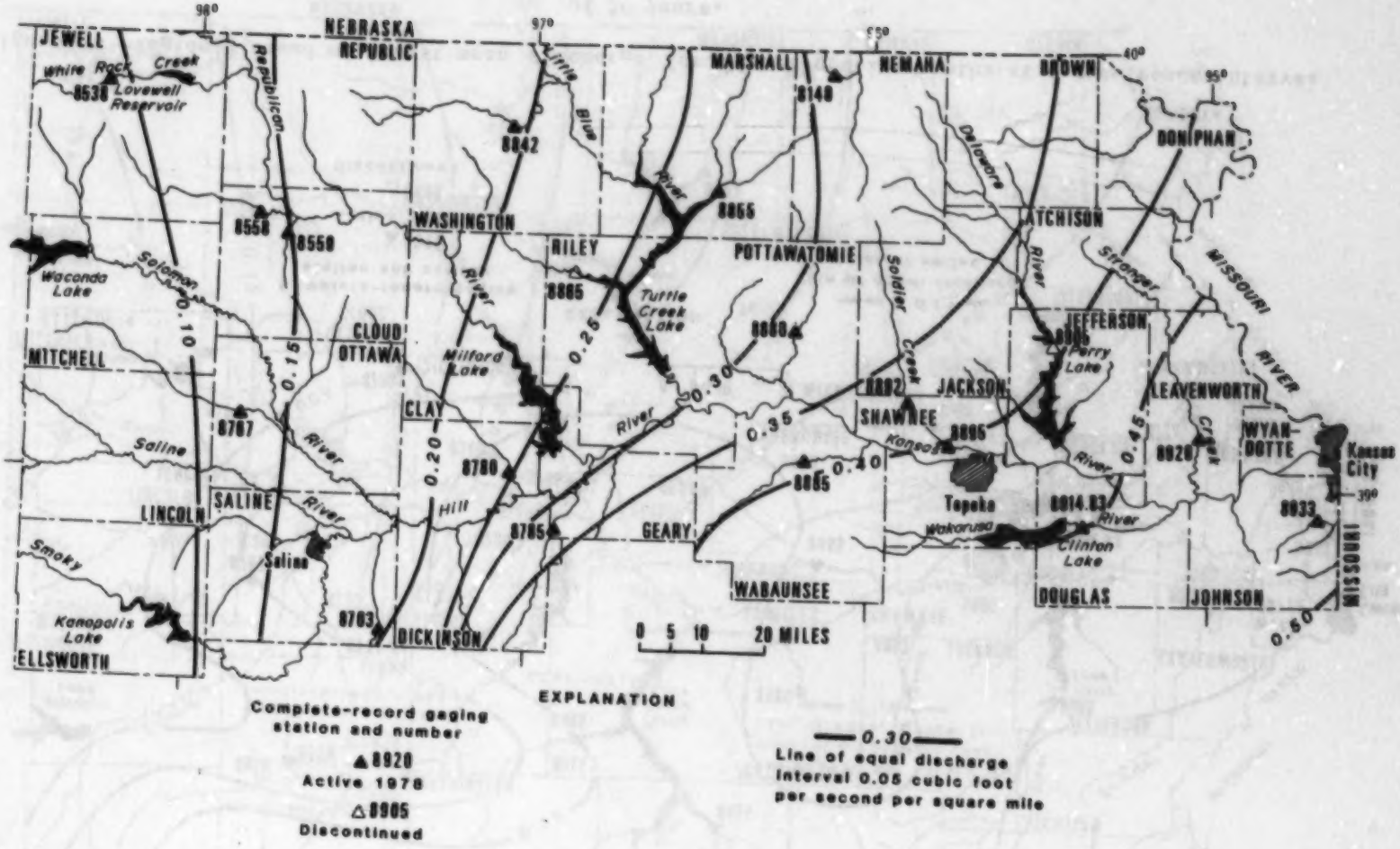

Figure 8.--Regional trend of lowest mean discharge for 24 consecutive months at a recurrence interval of 2 years.

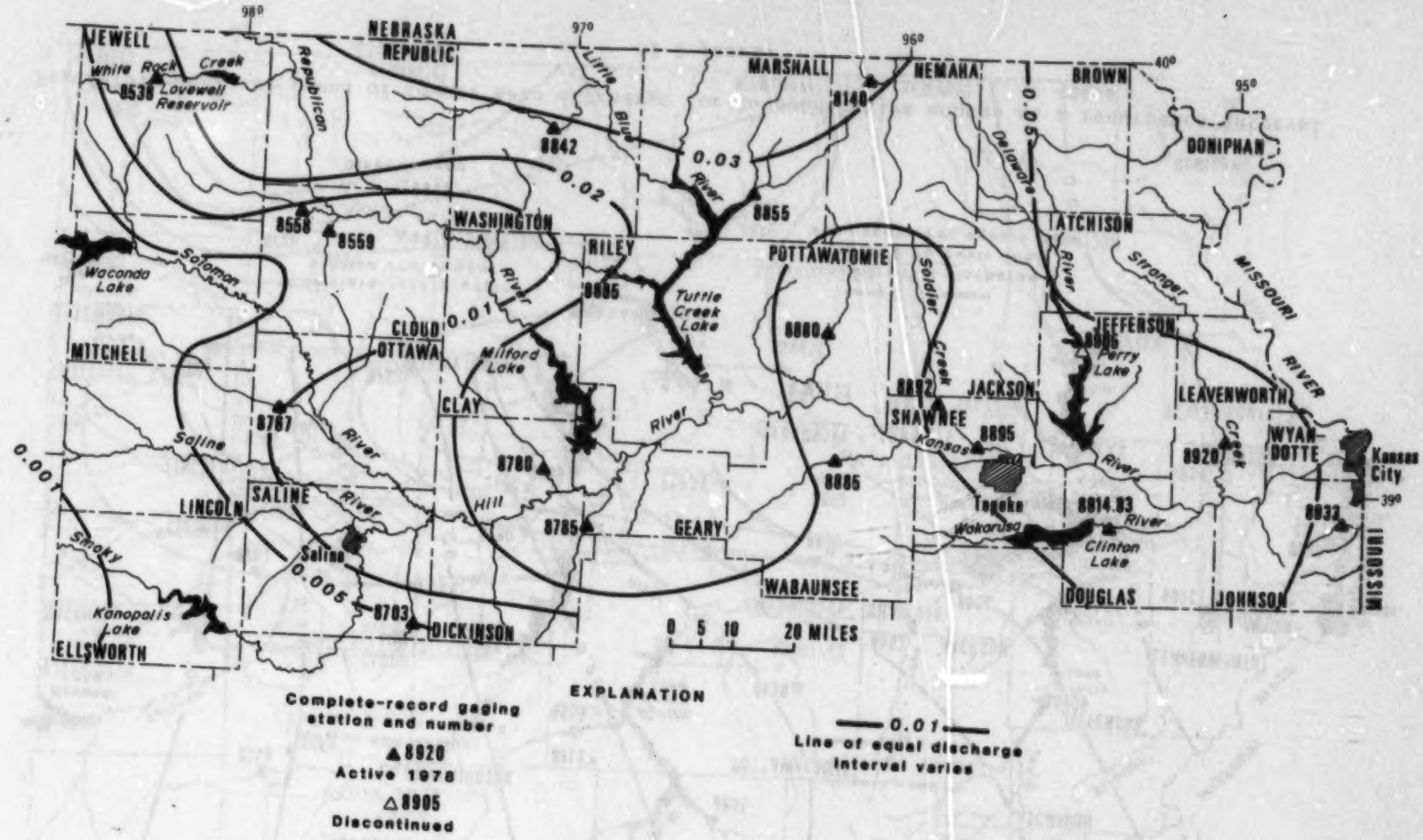

Figure 9.--Regional trend of lowest mean discharge for 24 consecutive months at a recurrence interval of 50 years.

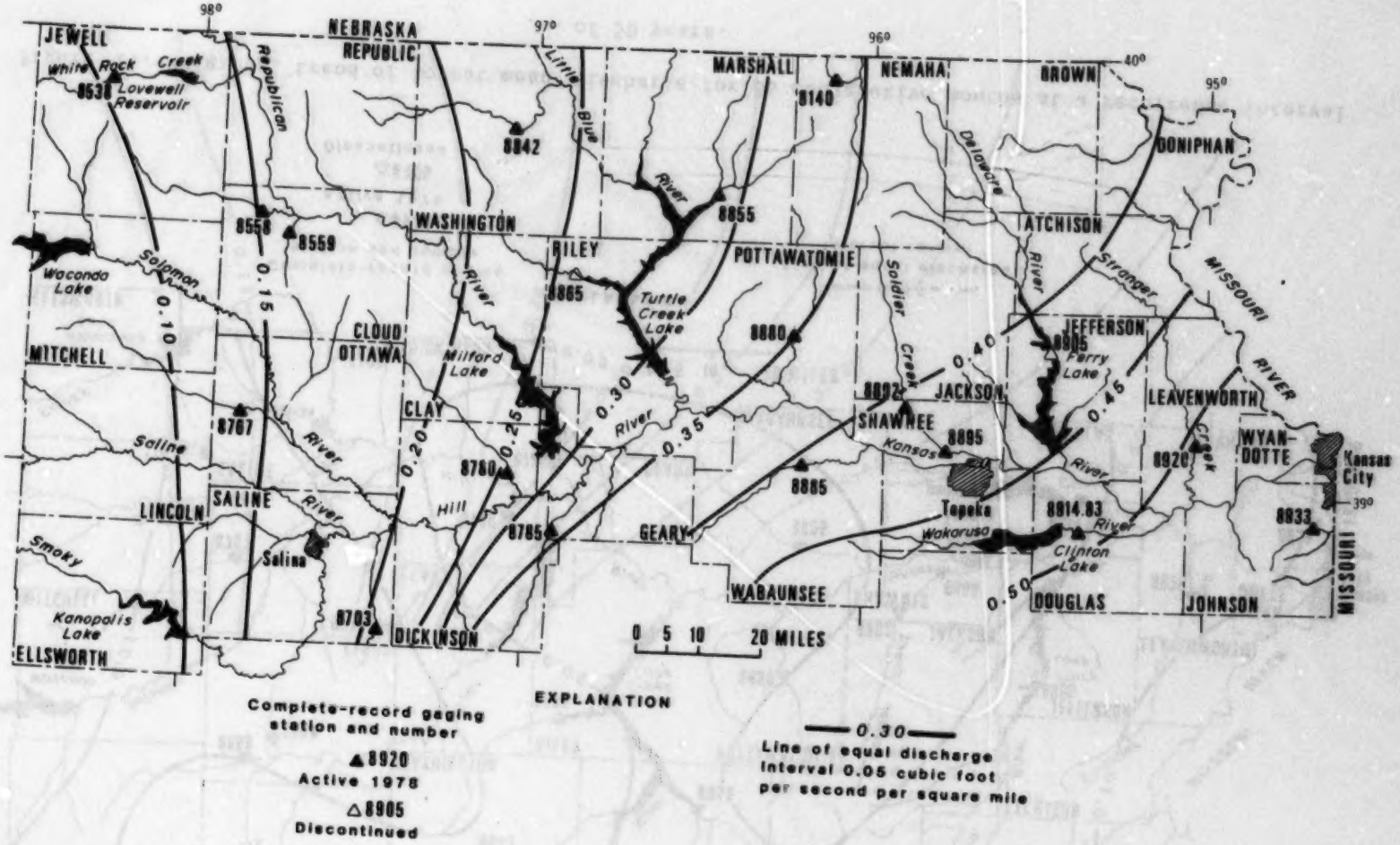

Figure 10.--Regional trend of lowest mean discharge for 36 consecutive months at a recurrence interval of 2 years.

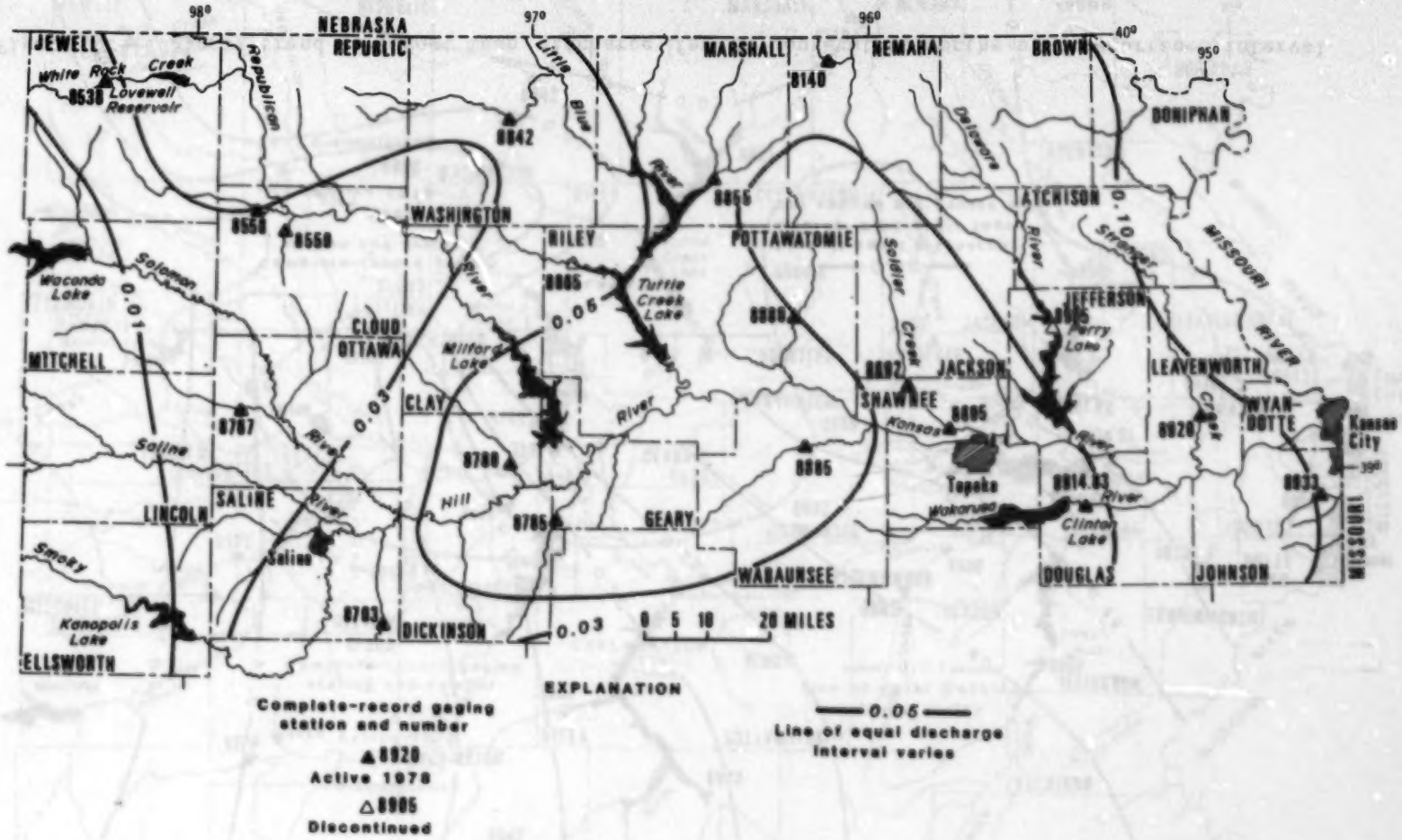

Figure 11.--Regional trend of lowest mean discharge for 36 consecutive months at a recurrence interval of 50 years.

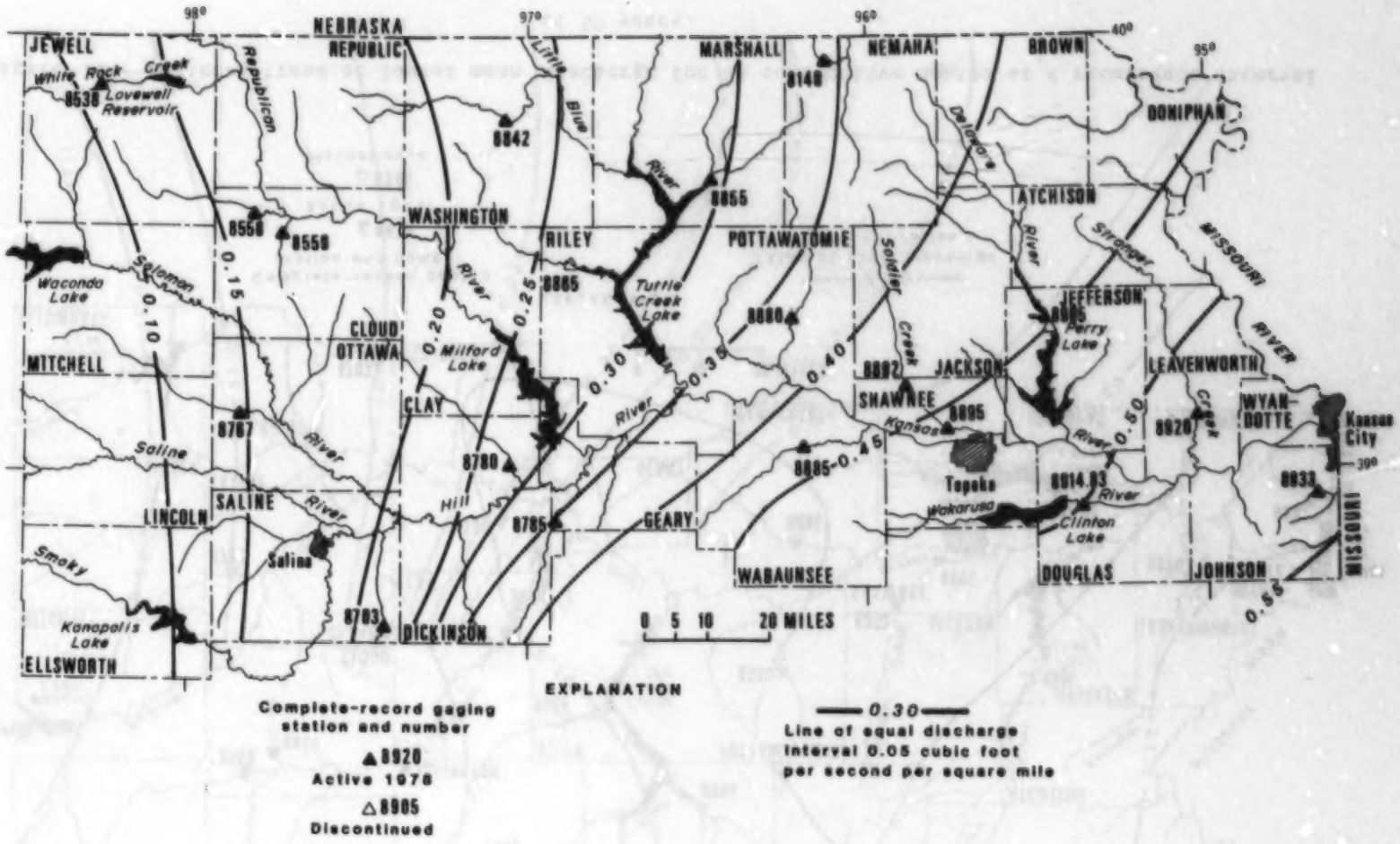

Figure 12.--Regional trend of lowest mean discharge for 48 consecutive months at a recurrence interval of 2 years.

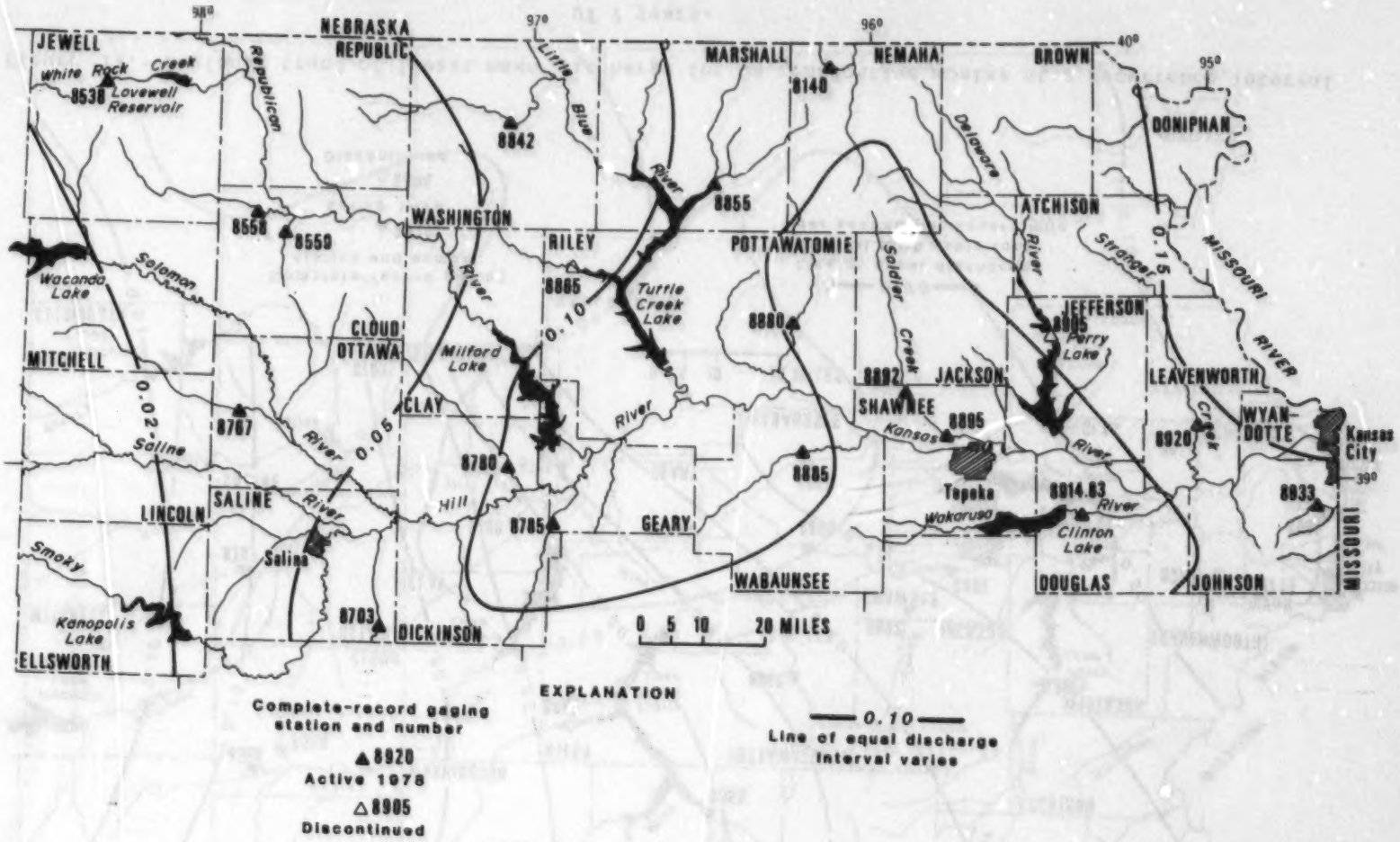

Figure 13.--Regional trend of lowest mean discharge for 48 consecutive months at a recurrence interval of 50 years.

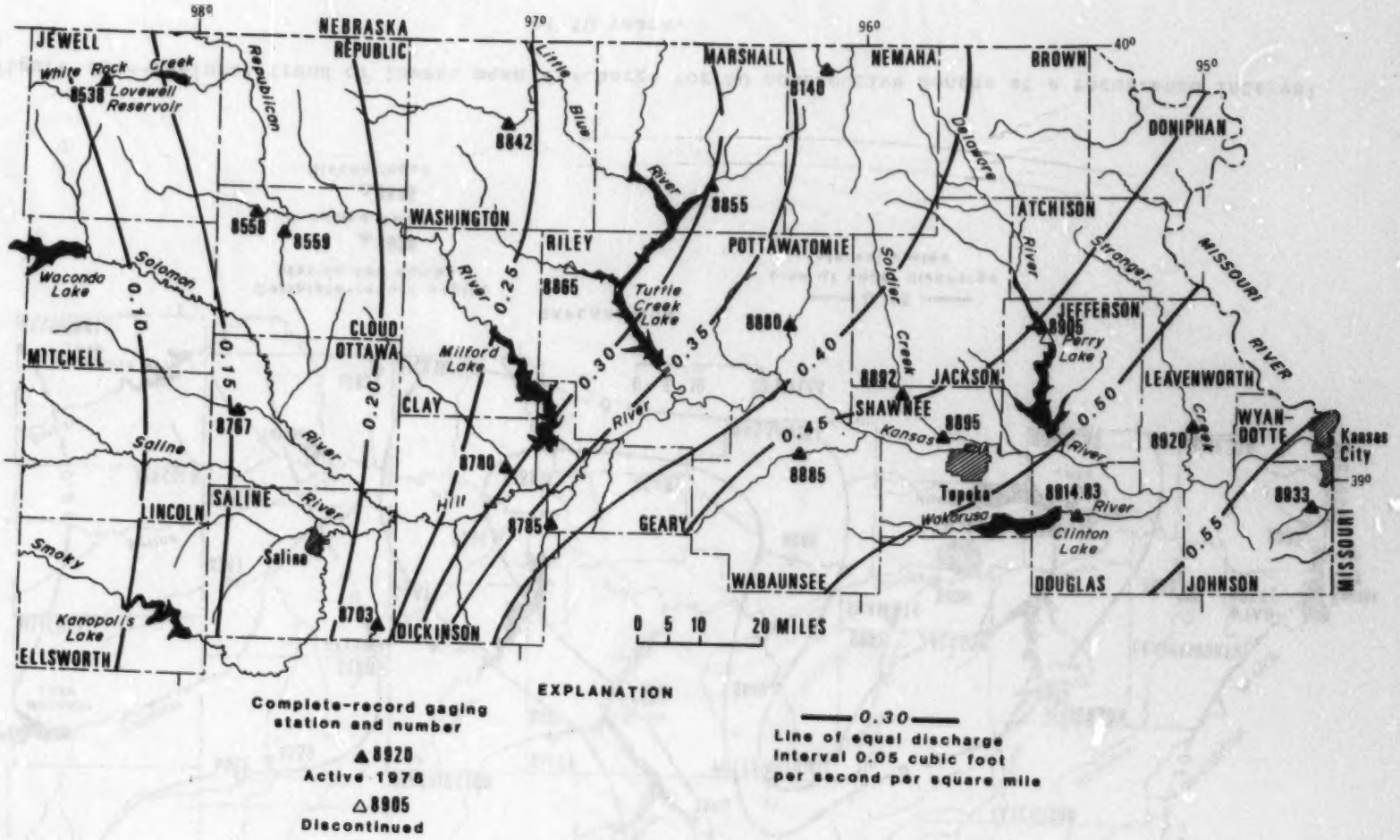

Figure 14.--Regional trend of lowest mean discharge for 60 consecutive months at a recurrence interval of 2 years.

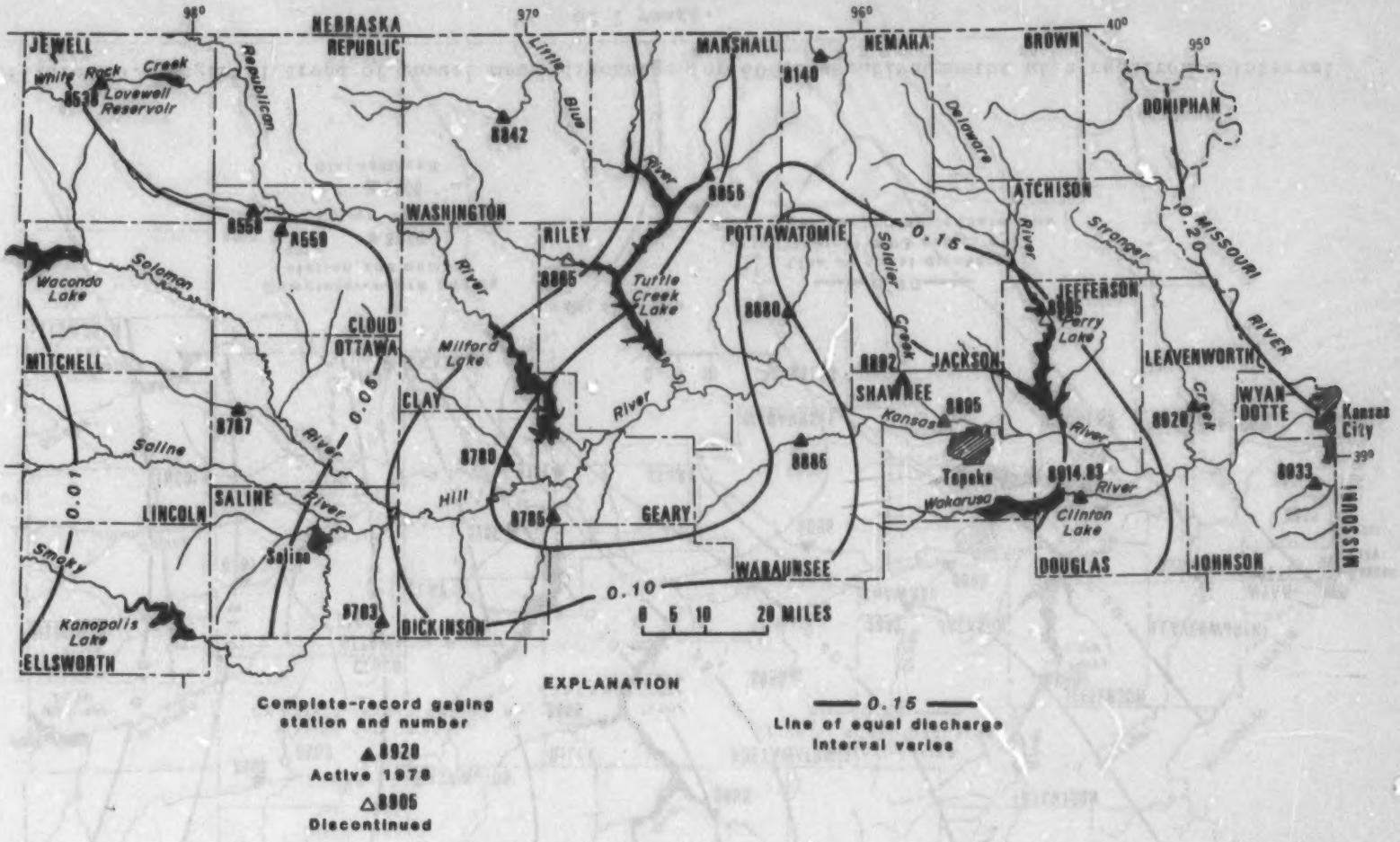

Figure 15.--Regional trend of lowest mean discharge for 60 consecutive months at a recurrence interval of 50 years.

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